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EvTEC
EVALUATION PLAN

Plasma Enhanced Melter™

Integrated Environmental Technologies, LLC

Civil Engineering Research Foundation

Idaho National Engineering and Environmental Laboratory

Allied Technology Group, Inc.

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1.0 INTRODUCTION

This document defines the procedures and protocol for verifying the performance of the Integrated Environmental Technologies, LLC Plasma Enhanced Melter™ (PEM™) Technology for waste treatment.

1.1 Background

A cooperative program of technology performance verification was established in 1998 among Washington State Department of Ecology (WSDOE), Integrated Environmental Technologies, LLC (IET), Allied Technology Group, Inc. (ATG), and the Civil Engineering Research Foundation, (CERF). The program is designed to test and evaluate a collaborative approach to carrying out the provisions of *HB1792*, which requires Ecology to establish a program to verify the performance of new environmental technologies, with special reference to technologies addressing the Hanford site. The program goal is to promote and enhance the identification of innovative environmental technology, the verification of its performance, and the transfer of beneficial technology into the marketplace.

1.2 Verification Program Objectives

This cooperative technology verification program will have as its specific goal to verify the performance of the Plasma Enhanced Melter™ process for waste treatment. IET will perform demonstration tests and provide supplementary data to meet the following objectives:

- Demonstrate the efficacy of the process for various types of waste
- Provide sufficient information about system performance to show PEM™ system equivalency to other Best Demonstrated Available Technologies, namely incineration

- Characterize amounts and properties of outlet streams
- Characterize Products of Incomplete Reaction (PIRs) in outlet streams
- Characterize metals content in outlet streams
- Identify critical process control variables
- Document variability of process
- Address public concerns regarding thermal treatment technology, air emissions, and safety
- Provide or document information useful for potential customers and stakeholders, such as health and safety controls for operators and the public, reliability, availability, maintainability, and major cost factors.

1.3 Verification Program Implementation

The program is being implemented using the consensus-based evaluation process of the CERF Innovation Centers. The process is being managed by CERF's Environmental Technology Evaluation Center (EvTEC), operating under a cooperative agreement with USEPA. The implementation includes a Technical Evaluation Panel of regulatory, stakeholder, and technical expert representatives that will evaluate and verify the PEM^{TM} system using performance data.

Verification of the capability and efficacy of the PEM^{TM} system will be accomplished through a combination of direct EvTEC oversight of demonstration and testing, review of test data, and review of supplementary data from operations and tests performed by IET without direct EvTEC oversight.

The information obtained from EvTEC-monitored demonstration tests and other supplementary data will be reviewed by the Technical Evaluation Panel to develop a final Evaluation Report for the PEM technology. EvTEC will prepare the Evaluation Report and Summary Verification Statement and deliver them to WSDOE. Depending on the results, WSDOE may then issue a statement of

performance according to *ESHB1792*. The verification report and statement will not approve, recommend or endorse the technology, and WSDOE, EPA and EvTEC will not guarantee performance.

1.4 Progress to Date

Progress and activities of the verification program as of August 2000 are listed below:

- The verification program was initiated and the Technical Evaluation Panel was selected in 1998.

- IET, Allied Technology Group (ATG), and their trial burn testing subcontractor Focus Environmental prepared a draft test plan (IET 1998) for the panel to review and for planning the verification tests. This test plan was based on the draft trial burn plan for the PEM™ system to be installed into the ATG mixed waste treatment facility at Hanford, Washington. This implementation of the PEM™ system has been trademarked as the ATG GASVIT™ system.

- The Technical Evaluation Panel met in October 1998 to review the draft test plan and recommend to IET the kinds of data and scope of testing needed to evaluate the PEM™ system performance. Panelist comments were provided during the meeting, submitted to CERF following the meeting, and documented (Woolley 1998).

- IET performed several test plan revisions between October 1998 and March 2000, as they determined how to best incorporate the verification testing into their development, demonstration, and marketing activities. While IET performed various demonstration tests with their melter systems during this time, no tests were monitored by EvTEC.

- EvTEC personnel monitored demonstration testing conducted in IET's 10 ton per day, commercial-scale prototype system installed in the IET Technology Center in Richland, Washington during the first two weeks of April 2000. The system was tested using a synthesized organic liquid feed and a bulk solid circuitboard waste stream. These tests were performed based on the then-current draft of the EvTEC test plan (IET 2000) and based on equivalency test objectives defined by ATG, Focus Environmental, and EPA Region 10. Process monitoring and

control, process sampling and analysis, and offgas sampling and analysis were performed to control and document operating conditions, determine air emissions, and evaluate mass balances and system performance during these tests. Following the equivalency and circuitboard waste tests, IET fed both municipal solid waste and hospital waste to the system to demonstrate process operation with these feedstreams. While operating conditions were controlled and documented, no process stream or offgas sample collection and analysis was performed.

- The draft EvTEC test plan was modified to produce this evaluation plan document in July 2000 to update the verification program objectives, specify the kinds of performance information that IET needs to provide to the Technical Evaluation Panel, and specify and direct the activities of the panel as performance data becomes available.

2.0 PERFORMANCE CRITERIA FOR THE VERIFICATION PROGRAM

The verification program will meet the program objectives listed in Section 1 by reviewing test data provided by IET from EvTEC-observed tests, from other demonstration tests, and from engineering estimates with respect to criteria and issues listed in Table 1. This table presents the criteria and issues of greatest interest, provides the kinds of information needed to determine how the system satisfies each criteria or addresses each issue, indicates if the April 2000 demonstration tests that were observed by EvTEC representatives can provide the needed data. If the April 2000 tests do not provide the needed data, or if the data is considered by IET to be proprietary, then those criteria may not be evaluated in the verification process.

The two most important evaluation criteria are (a) how well the system meets the treatment objectives (listed in the table) and (b) how well the system meets emission limits. Emission limits assumed to apply for the purposes of this verification are shown in Table 2.

Based on the amounts and kinds of data expected from the April 2000 tests, data from other supplemental tests or engineering estimates will be needed to evaluate PEM^{TM} system performance for most of the criteria in Table 1. Data provided that is supplemental to the April 2000 tests should

be accompanied by sufficient narrative and quality information for the panel to understand the level of quality and usefulness of that data.

Data submitted by IET to the panel for the verification program need to be reduced and evaluated to the extent the panel need not do extensive additional data reduction. For example, weigh scale measurements of feedrates need to be converted to feedrates, offgas velocity head measurements need to be converted to velocity and flowrate measurements, laboratory analyses should be converted to concentrations and mass flowrates, and temperatures, pressures, flowrates, and concentrations need to be averaged over applicable time periods or test periods. Data reduction to convert raw data to formats or units needed for evaluation is not within the scope of activities performed by EvTEC representatives.

IET has performed many different demonstration tests during the development and testing of the PEM™ system technologies. Table 3 lists the different kinds of feeds or surrogate feeds that have been processed in three different sizes of PEM™ melters – a development-scale 0.5 ton/day (nominal) melter, a demonstration-scale 2 ton/day melter, and the full-scale 10 ton/day melter. This table also shows the offgas measurements that were performed during tests when these different feed materials were processed. Data from these tests, if included in the EvTEC verification program, will be used as supplemental information in addition to the data from the April 2000 tests to evaluate the system performance with respect to the criteria listed in Table 1.

Table 1. Performance criteria and other data that will be used for PEM™ verification.			
Verification criteria/issue	**Source of data (a)**	**Comments**	**Do the April 2000 tests provide this data?**
Air emissions need to comply with expected regulatory/permit limits.	Emissions measurements for different test conditions.	Assumed emission limits are shown in Table 2.	Yes, but only for circuitboard wastes and for surrogate organic liquid waste. Data still needed for processing incinerator ash, liquid feed (spiked with lead and cadmium), medical waste, and municipal wastes.
Treatment objectives need to be met.	Test data from demonstration tests: waste feedrates, volume reduction, final waste form properties and compositions, mass balances (that show the fate of C, fixed C, PODCs, PCBs, Cl, S, metals, radionuclides), fate of secondary wastes	Assumed treatment objectives are: a. Destroy toxic and non-toxic organic compounds b. Reduce the waste volume c. Convert waste into non-leachable glass, non-leachable or recyclable metal, and CO_2/H_2O d. Any scrub solution discharges below toxicity characteristic leachability procedure (TCLP) limits Detection limits and material retention time in the melter often will limit the accuracy of some measurements.	
Surrogate feeds used during demonstration tests need to be physically and chemically representative of candidate wastes.	Comparison of feedrates and physical properties of surrogate feeds, flux materials, and actual wastes.	Physical properties include: liquid/solid, liquid viscosity, solid particle size, heterogeneity, packaging. Chemical properties include elemental composition (metals As, Ba, Co, Cs, Ce, Cd, Cr, Cu, Pb, Mn, Ni, Se, Ag, V, Tl, and Zn, and slag formers Al, Ca, Fe, K, Na, Si; Cl, F), inorganic and organic carbon, proximate analysis (ash, moisture, fixed carbon, volatile content), and ultimate analysis (C, H, N, O, S, ash)	The circuitboard and liquid feeds are not very similar to many other kinds of wastes. Most PEM™ performance verification for other waste types will need to be done with supplemental data for tests of other types of feed materials.
Maximum and minimum feedrates in absolute terms and compared to design feedrates and power input.	Comparison of feedrates and feed compositions, to power input, tapping rates, product compositions, melter residence times, offgas emissions, system operating conditions and process controls	If data on operating limits (feedrates, feed compositions, additives, reactants, operating temperatures, etc.) is not included in demonstration tests, then operating conditions during the April 2000 and other tests may be used to show conditions that are achievable, although this may not show the full potential operating ranges.	Not in scope of the April 2000 tests. Determinations of operating limits will need to be done with supplemental data.
Minimum amounts of any feed additives or gaseous reactants (O_2 or H_2O) needed for process control or final waste form tailoring	Measurements of flowrates and compositions of additives and reactants for different feed materials and flowrates, desired operating conditions, and properties and flowrates of product slag, metal, syngas, scrub solution, and fly ash.		

Table 1. Performance criteria and other data that will be used for PEM™ verification (continued).			
Verification criteria/issue	**Source of data (a)**	**Comments**	**Do the April 2000 tests provide this data?**
Process conditions during operation with specified feedrates and compositions need to be within design, stable limits.	Measure and record process conditions	If data on operating limits is not included in demonstration tests, then operating conditions during the April 2000 and other tests may be used to show conditions that are achievable, although this may not show the full potential operating ranges.	Yes, but only for circuitboard wastes and for surrogate organic liquid waste. Data still needed for processing incinerator ash, liquid feed (spiked with lead and cadmium), medical waste, and municipal wastes.
What are operating and lifecycle costs and waste treatment unit costs?	Recorded labor and nonlabor operating costs, including secondary waste disposal costs, and estimates of capital and lifecycle costs.	IET needs to determine what information can be released for panel review.	Cost estimates should be based on both the April 2000 tests and on other tests or engineering estimates.
What are most likely process/equipment failure modes and how will undesired results of such failures be mitigated?	Recorded process upsets or failures, predictions of those failures that may occur, estimate outcomes and determine mitigating actions.	Short-duration tests are usually not long enough to identify all likely upset scenarios, so these may need to be estimated.	Estimates need to be made based on available and nonproprietary data from all PEM™ operating experience.
What are reliability, availability, and maintenance (RAM) limits and requirements?	Recorded or estimated equipment failure/maintenance occurrences.		
What are potential exposures to workers from operations and maintenance, and how will they be mitigated?	Recorded or estimates types and durations of worker interactions with waste feed, equipment, and secondary wastes, and estimates of worker exposures resulting from those activities.		
What are worker training requirements?	IET operating experience		

Table 2. Air emission standards considered in verification program.

Pollutant or surrogate (a)	MACT emission standard (b and EPA 1999)		Applicable other standard	
	Existing sources	New sources	Value	Reference
D/F	0.20 ng TEQ(c)/dscm; or 0.40 ng/dscm and temperature at inlet to the PM control device ≤ 400°F	0.20 ng TEQ/dscm	---	---
Hg	130 µg/dscm	45 µg/dscm	---	---
PM	34 mg/dscm (0.015 gr/dscf)		---	---
SVM (Cd, Pb) (d)	240 µg/dscm	24 µg/dscm	---	---
LVM (As, Be, Cr) (d)	97 µg/dscm		---	---
HCl/Cl_2 (e)	77 ppmv	21 ppmv	---	---
HC (f,g)	10 ppmv (or 100 ppmv CO)		---	---
DRE (h)	99.99% for each specific POHC (I) except 99.9999% for specific dioxin-listed wastes		---	---
Be	See LVM standard		10 g/24-hrs	40 CFR 61.32
Total radionuclides	---	---	0.1-10 mRem/yr (j)	40 CFR 61.92
PCB DRE (k)	---	---	99.9999%	40 CFR 761.70

a. Some parameters are used as surrogates to indicate compliance with hazardous air pollutants. PM is used as a surrogate for non-enumerated metals Sb, Co, Mn, Ni, and Se. CO and HC are used as surrogates for organic hazardous air pollutants. DRE is used to indicate the control of organic hazardous air pollutants other than D/Fs, which are controlled by a specific standard.
b. All emission levels are corrected to 7% O_2.
c. Toxicity equivalency quotient, the international method of relating the toxicity of different D/F congeners to the toxicity of 2,3,7,8-tetrachlorinated dibenzo-p-dioxin (2,3,7,8-TCDD).
d. Total metals regardless of speciation.
e. Total HCl and Cl_2 in HCl equivalents (Cl_2 in ppm is multiplied times 2 to get HCl equivalents).
f. Hourly rolling average. HC is reported as propane.
g. Facilities that choose to comply with the CO standard by continuously monitoring CO rather than HC emissions must also demonstrate compliance with the HC standard of 10 ppmv during the comprehensive performance test.
h. DRE = Destruction and Removal Efficency.
i. POHC = Principal organic hazardous constituent.
j. Total radioactive emissions must cause the estimated effective dose equivalent received by any member of the public to exceed 10 mRem/yr. Pollutant dispersion after the emissions leave the stack, and prior to potential human exposure, is considered in addition to the actual amounts and kinds of radionuclides emitted. Several mixed waste facilities are limited to an effective dose equivalent as low as 0.1 mRem/yr in order to maintain the effective dose equivalent for the entire site, which may contain many radioactive facilities, below 10 mRem/hr.
k. PCBs = Polychlorinated biphenyls.

Table 3. Tests performed during PEM™ technology development and demonstration.

Nominal melter size, ton/day	Feed material	Offgas measurements					
		Semivolatile organics (Method 23/0010)	Particulate or HCl/Cl_2 (Methods 5, 26, 0050)	Metals (Method 29)	VOCs (Method TO-14)	VOCs (Method 0031)	Offgas composition (CEMS)
0.5	Inorganic surrogates with spiked metals	D/Fs, PCBs		X	X		X
	Incinerator ash	D/Fs, PCBs			X		X
2	Wood and plastics	PAHs			X		X
	Medical wastes	PAHs		X	X		X
10	Medical wastes	D/Fs, PAHs, some other SVOCs	X	X	X		X
	Municipal solid waste	No offgas testing					
	Methanol spiked with POHCs (April 2000)	D/Fs, PAHs, PCBs	PM and HCl/Cl_2			X	X
	Circuitboard fabrication waste (April 2000)	X	PM and HCl/Cl_2	X		X	X
	Municipal solid waste (April 2000)	No offgas testing					
	Hospital waste (April 2000)						

3.0 DETAILED ENGINEERING DESCRIPTION OF THE PEM™ SYSTEM

The PEM™ process treats and stabilizes a wide variety of mixed wastes. A flow diagram of the process is shown in Figure 1. Materials treated may contain both organic and inorganic matter without regard to their net heating value or their exothermic contribution to the treatment process. The process is designed to accomplish three main functions, (a) destroy toxic and non-toxic organics, (b) reduce the waste volume, and (c) vitrify the inert and radioactive residues from the destruction process. The PEM™ process product is a vitrified glass or rock like material, which is highly durable and leach resistant. Process byproducts include (a) solidified metal, (b) a fuel gas, referred to as synthesis gas, or "syngas," that is either used as a fuel for electricity generation or converted to water and carbon dioxide, a stable form, before being discharged to the atmosphere, and (c) syngas control system secondary wastes including scrubber solution, baghouse ash, and HEPA filters. The baghouse ash and HEPA filters may be recycled to the melter to appreciably reduce the amount of these wastes that need to be disposed.

The PEM™ process accomplishes two distinct operations simultaneously, gasification and vitrification. In the gasification operation, organics in the waste are gasified in the absence of oxygen (reducing environment) to produce a fuel gas called syngas. In the vitrification operation, inert wastes (metals and minerals) are melted and incorporated into a leach-resistant vitrified product. Unlike a combustion process that produces heat, the gasification and vitrification process absorbs heat (an endothermic process) and thus requires an outside heat source.

In the PEM™ system, a plasma-arc provides the outside source of heat to process primarily organic wastes. In addition, the PEM™ process chamber utilizes joule heating to maintain the temperature of the molten bath. The thermal energy from the plasma converts the organic waste into light organics and primary elements. Steam is introduced into the chamber allowing the gasification (or steam reforming) reaction to take place. With some input wastes, there is sufficient water within the matrix so that additional steam is not required.

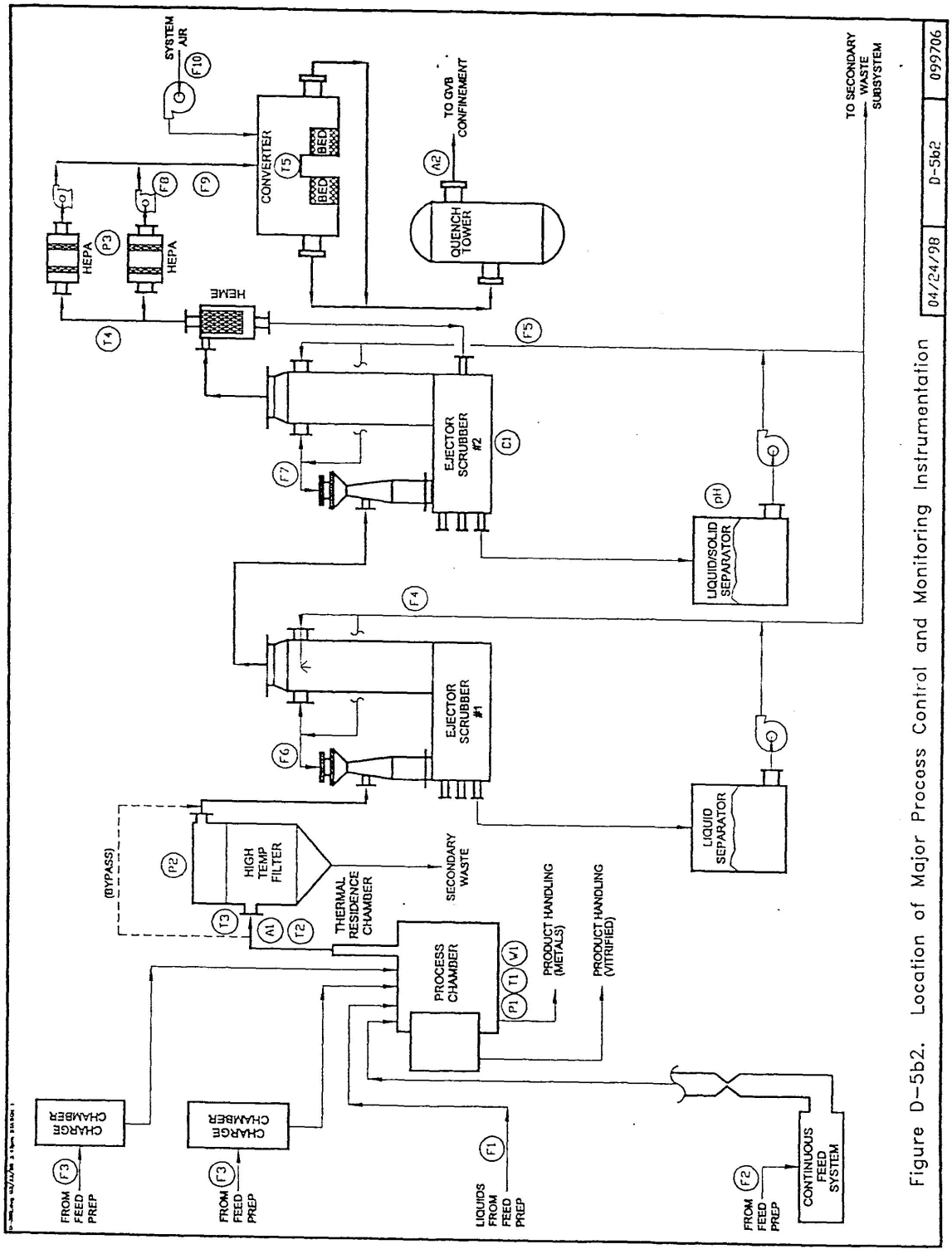

Figure 1. PEM^{TM} process flow diagram (formerly Figure D5b-2).

The combination of plasma and joule-heating processes the waste materials into the gas and glass products. The molten glass product is withdrawn and cooled to form a monolith in the receiving canister. This product is stable and highly leach-resistant. During the process glass forming additives may be introduced to control glass chemistry.

The syngas by-product discharged from the process chamber where the plasma arc is generated is a mix of hydrogen, carbon monoxide, steam, acid gases, particulate matter including any entrained or condensed metals, and potential PIRs. This mixture is discharged from the process chamber at temperatures exceeding 1,000°C (1,800°F) although the reaction zone is much hotter. The syngas is then either treated, cleaned and finally converted to CO_2 and water prior to being discharged to the atmosphere, or alternatively used as a fuel to produce electricity via a gas turbine generator set (genset). The treated syngas released from the PEM™ system is described as the "system exhaust."

The PEM™ process consists of five main subsystems:

- Feed subsystem
- Process chamber subsystem
- Product handling subsystem
- Syngas processing subsystem
- Utilities subsystem.

3.1 Feed Subsystem

The feed subsystem introduces feedstock and additives into the process chamber at a pre-determined feed rate. The following four different types of feeders are used:

- A feed tank/pump assembly is used to feed liquid/sludge wastes.
- A continuous screw feeder equipped with an airlock hopper assembly is used to introduce solids.

- A redundant set of batch feeder mechanisms are used to feed pre-packaged waste canisters.

- Glass former additives are metered into the continuous solids feeder by a gravimetric feeder which introduces the material into the process chamber. Glass forming additives are also introduced through the batch feeder.

3.1.1 Liquid Feeder

The liquid feeder consists of a feed tank and a set of redundant feed pumps. A portable, top mounted, pump is used for transferring liquid from incoming containers to a feed tank.

The process flow is based on receiving the incoming liquid and sludge wastes in 55 gallon drums or flo-bin containers. The liquid is pumped into the feed tank and the feed tank mixer is turned on to blend the liquid into a uniform consistency. A strainer is mounted at the discharge of the container pump to remove solids from the liquid waste to avoid clogging the nozzles and small piping downstream of the liquid feed pumps. Spent sludge filters are removed from the filter housing, placed in a one cubic foot canister, and staged as feed for the solids batch feeder.

Before feeding liquid to the process chamber, the feed pump discharge valves are lined up in a recirculation mode and the feed pump is turned on to recirculate the liquid through the discharge piping and back into the feed tank. When all feed conditions meet the required specifications and when the process chamber conditions are within the specified limits, the waste feed cut-off valve is opened to convert the flow from the recirculation to the feed mode. When feeding operation is to be stopped, the feed cut-off valve is placed in the closed position and the liquid is allowed to recirculate. At this time the feed pump can be turned off, if needed.

3.1.2 Continuous Solid Feeder (Bulk Solids)

The continuous solids feeder subsystem primarily consists of a hopper, a nitrogen purged airlock, a solids feeder extruder, and a flux additive feeder that introduces raw glass additives to the process to ensure a leach resistant product. When initiating a continuous solid waste feed campaign, wastes are taken from the surge storage and placed in the feed hopper. The waste falls into the hopper, through the nitrogen-purged airlock, leading into the solids feeder extruder.

A cutoff isolation valve is placed immediately downstream of the feeder extruder to comply with permit requirements for an automatic waste feed cutoff (AWFCO) in the event of an upset in normal operating ranges. Normal permit conditions must exist to engage the permissive for solid feeding. Immediately adjacent to the feed isolation valve, two water cooled jackets surround the process chamber solid feed port to reduce heat propagation to and upstream of the feed isolation valve.

Glass former additives (flux), which are required during the processing of certain wastes, are introduced into the process chamber via the continuous solids feeder hopper.

3.2 Process Chamber Subsystem

The process chamber subsystem is the heart of the PEM™ system, where feed materials are processed producing synthesis gas, a ceramic/glass product, and metal. Two sources of energy are utilized to process the feed: the DC (direct current) arc plasma zone, and the AC (alternating current) joule-heated zone. The DC arc plasma is created by applying a DC potential across the three 6-in. diameter graphite arcing electrodes with a single electrode at one polarity and the other two electrodes at the opposite polarity. A stable plasma arc is then formed between the molten bath and arcing electrodes. The second source of energy to the process chamber is supplied directly to the molten glass via three 6-in. diameter graphite joule-heating electrodes submerged in the melt. A three-phase AC potential is placed across the joule-heating electrodes which results in current flow through the glass. The molten glass acts as a resistor such that power is supplied directly to the molten glass. Organic constituents which are subjected to the DC plasma arc and joule heating are pyrolized and steam reformed producing CO, H_2, HCl, and H_2S. Inorganic constituents decompose to oxides and dissolve into the glass phase.

The process chamber is a water-jacketed 304L stainless steel vessel lined with refractory. The process chamber encompasses two subsystems for product removal, a vacuum assisted, weir overflow for

slag removal and an inductively heated bottom drain for metal. The process chamber proper consists of two zones, the melt tank which contains the molten slag (or glass) and molten metal (which lies on the bottom of the melt tank), and the plenum, or vapor space above the melt. The chamber lining is composed of several different types of refractory and insulating materials. These materials serve to reduce energy losses to the water jacket as well as to contain the molten glass and metal phases. The plenum area of the process vessel is lined with both insulating materials as well as material to protect the steel shell from corrosive feed decomposition gases and vapors.

The process flow for the process chamber is based on the receipt of feed from the solid waste feed systems and/or the liquid feed system, and glass former feed system. Feed enters the process chamber and falls to the molten glass surface, forming a feed pile where the feed material is exposed to energy from the DC plasma and the joule-heated glass. Steam is injected into the process chamber plenum, in the region of the feed pile, to steam reform organic constituents. Organic constituents in the feed are thermally destroyed, in an oxygen-deficient atmosphere, to produce mainly CO, H_2, HCl, and H_2S. Inorganic oxides dissolve into the slag phase. Metals present in the feed melt and settle to bottom of the tank.

Power is input into the process from two sources, the DC plasma and AC joule heating of the molten glass. The relative fraction of power from these two sources is controlled by the operator, and varies based on the type of feed being processed. Feeds that contain a high percentage of organic material require a higher percentage of power from the DC plasma, while feeds that contain a high fraction of inorganic material will be processed with a higher fraction of processing power from the joule-heated glass tank. The refractory temperature and the plenum temperature will also determine the amounts of power from each source.

All of the electrodes enter the process chamber through penetrations in the lid. The three AC joule-heating electrodes enter the chamber at the perimeter of the melt tank and are equally spaced 120° apart. They protrude through the plenum, protected by inconel alloy sheaths, into the molten glass. The joule-heating electrodes are protected from gases in the process chamber plenum by inerting the annular space between the electrodes and the sheath with an overpressure of nitrogen.

The three DC electrodes also enter the process chamber through the lid, but near the center of the chamber. Like the AC electrodes, the DC electrodes are equally spaced 120° apart. Additional nitrogen is injected into the furnace through the DC electrode penetrations in the lid of the process chamber.

The DC plasma power is controlled via the current and the voltage. The plasma voltage is proportional to the length of the arc, which is controlled by adjusting the physical distance between the tips of the electrodes and the molten glass surface. System operators will set the desired plasma voltage set point and manually adjust the current to achieve the desired power. The control system will correspondingly adjust the vertical position of the electrodes to maintain the plasma voltage set point. The plasma polarity can also be changed to accommodate the various waste feed types. IET plans to operate the PEM™/GASVIT™ system using the "worst case" plasma polarity for each Equivalency test Condition. The polarity is displayed by the control system, and will be logged during each Equivalency test run. As the anodes operate at higher temperatures than the cathodes, two anodes and one cathode will be used for the high temperature test conditions. One anode and two cathodes will be used for the low temperature test condition.

Adjusting the AC current flowing through the molten glass bath controls the joule-heating power. The resistance of the molten glass determines the corresponding potential, and power added. The resistance of the glass is controlled by its composition and temperature. Therefore, operating staff will set the desired power as a set point, and the AC power supply will achieve this power input by adjusting AC current to achieve that set point. In addition to passing AC current between the joule-heating electrodes, the electrical configuration will enable operators to pass AC current to the floor of the melt tank. The bottom of the melt tank is equipped with three electrical connections to allow this operational mode. Current can be transferred to the bottom of the furnace if the temperature of the lower melt needs to be increased, possibly to assist in pouring material through the bottom drain.

Process syngas is removed from the process chamber via the process syngas removal vent, and is ducted to an insulated thermal residence chamber where the steam reforming reactions can continue to take place. Indicators monitor process chamber temperature and pressure, and the temperature of the syngas exiting the thermal residence chamber. The process chamber is maintained under a slight vacuum by the process vent system to assure that no process gases or vapors escape untreated from the chamber. The process chamber is also equipped with an emergency off-gas vent to prevent an over pressurization of the process chamber in the event of a plug in the syngas system downstream of the process chamber.

The injection of nitrogen into the plenum at the joule-heating electrode penetrations, the plasma electrode penetrations, and the steam injection penetrations maintain inert conditions in the process chamber ports.

The external surfaces of the process chamber are water cooled via the vessel jackets. The cooling water also provides a safety backup for containment of the melt in the event of a catastrophic failure of the melt tank refractory. The water cooling jacket is made up of 13 distinct circuits, three in the process vessel lid, four in the process vessel walls, four in the process vessel floor, and two in the over flow section. The inlet temperature of the process water as well as the outlet temperatures for each cooling water circuit are continuously monitored. In addition to the water cooling of the process chamber vessel, a high-purity process water stream cools the electrical connections to both the plasma and joule-heating electrodes.

A nitrogen-cooled thermal dam is located at the interface between the main process chamber and the overflow section of the system. This dam prevents glass from flowing around the weir. The nitrogen supply pressure to this dam is monitored along with its outlet temperature. The nitrogen exhausted from the dam is cooled via a gas/water heat exchanger and either recycled into the electrode purges or vented to the building exhaust.

3.3 Product Handling Subsystem

The product handling subsystem consists of a bottom freeze valve and an overflow drain valve attached to the process chamber. These two discharge points are used to remove molten product from the chamber. The molten product is poured into disposal containers and allowed to cool to a solid form.

3.4 Syngas Processing

The general syngas processing subsystem design (shown in Figure D-5b2) employs a three-stage process to remove particulate matter and acid gas impurities in the syngas, and convert the syngas to fully oxidized products (primarily water and carbon dioxide) for safe and regulatorily approved atmospheric release. The first stage of the purification process removes particles larger than 1 micron using a high-

temperature filter. The second stage includes a scrubber, mist eliminator, and HEPA filter and removes acid gases (such as hydrochloric acid and hydrogen sulfide), metals, and residual particulate matter. The third stage oxidizes the scrubber outlet syngas to convert it to water and carbon dioxide. Other customer-specified options for this third stage include using the syngas as a fuel in power generating equipment, in order to recover the some of the energy content of the input waste.

The syngas processing subsystem for the 10 ton per day PEM™ located at the IET facility that was used in the April 2000 demonstration tests was slightly different than the above description. In this system, a low-temperature pulse-jet baghouse was used in place of the first stage high temperature filter unit. The thermal retention chamber (TRC) outlet syngas was cooled using nitrogen-atomized water from around 800°C to around 200°C to prevent thermally damaging the baghouse. During these tests, the syngas was oxidized in either an enclosed ground flare or was used as a fuel in an internal combustion engine to produce electrical power using an electric generator (engine-generator set, or "genset"). The oxidized offgas from the ground flare and from the genset was discharged to the atmosphere.

3.4.1 First Stage Syngas Processing

The first stage syngas processing subsystem reduces and maintains the process chamber exhaust gases to a temperature range of (800-1,832°F) during waste processing operations and filters solid particulate from the gas stream exiting the process chamber before it is scrubbed by the caustic scrub system. Injecting steam into the gases exiting the thermal residence chamber provides temperature reduction. The filter is back blown periodically by a nitrogen jet pulsing system to clean the accumulated solids from the filter surface. These solids fall to the bottom of the filter housing, through an isolation gate valve, and into a receiving container. The receiving containers provide confinement features to minimize any potential airborne contaminant generated during the operation.

A low-temperature pulse-jet baghouse was used in place of the first stage high temperature filter unit during the April 2000 demonstration tests. The thermal retention chamber (TRC) outlet syngas was cooled using nitrogen-atomized water from around 800°C to around 200°C to prevent thermally damaging the baghouse.

3.4.2 Second Stage Syngas Processing

The second-stage system processing system provides acid gas scrubbing and particulate removal capability to clean the gas stream exiting the first-stage syngas processing system. The design of the second stage syngas processing system includes provisions for complete bypass of the first stage syngas processing unit. The two scrubbers, together, have a design removal efficiency for HCl of 99.96% at a flow rate of 50 lb/hr.

The process flow for the second stage syngas processing system involves wet gas scrubbing with tandem high-temperature ejector scrubber – packed tower absorption units, followed by a high efficiency mist elimination unit. A description of each unit is given as follows:

Dual High-Temperature Ejector Scrubber and Packed-Tower Acid Gas Scrubber. The first ejector reduces the incoming gas temperature from approximately 700ºC to below 60ºC using a sub-cooling system with a heat exchanger. This cooler is designed to remove approximately 231,000 Btu/hr of thermal energy from the gas stream during normal operation. This energy is transferred to the process cooling water subsystem. The ejector scrubber is fabricated using Alloy C-276 with high-alumina refractory in the inlet portion of the ejector. The packed tower and recirculation tank are constructed of 11 gauge Alloy C-276. The packed tower includes an Alloy C-276 packing support, acid resistant packing material, and non-metallic liquid distribution. The first ejector and packed tower system is equipped with a recirculation pump capable of delivering 50 gallons per minute at 85 psig.

The second ejector scrubber and packed tower set provides additional acid gas scrubbing to remove remaining acid gas constituents to regulatory release limits. Like the first ejector scrubber, the second ejector scrubber is fabricated using Alloy C-276 with high alumina refractory in the inlet portion of the ejector. Like the first packed tower and recirculation tank, the second packed tower and recirculation tank are constructed of 11 gauge Alloy C-276. The packed tower includes an Alloy C-276 packing support, acid resistant packing material, and non-metallic liquid distribution. The second ejector and packed tower system is equipped with a recirculation pump capable of delivering 50 gallons per minute at 80 psig.

High-Efficiency Mist Eliminator. The high-efficiency mist eliminator (HEME) provides final removal of fine mists from the syngas prior to final filtration and conditioning. The HEME is equipped with a Teflon® filter element and an inconel 625 mesh-type mist eliminator.

Gas Reheater. The syngas is reheated after exiting the second stage syngas processing unit to raise the temperature well above the gas dew point. This prevents water impingement of the subsequent HEPA filter. The stack gas reheater utilizes an Alloy C-276 housing with steam finned heating elements which can provide up to 10,000 Btu/hr to heat the gas stream to 140 ºF before filtration through the HEPA filters.

HEPA Filters. Parallel HEPA filter units are used for final particulate matter control. Each HEPA filter housing is constructed of 316 SS (in accordance with ASMG W509/5) with ground and polished internal surfaces. Each filter housing contains a prefilter, followed by a HEPA filter (99.97% efficiency for particulate > 0.3 micron), with a knife edge seal. Each filter housing has a bagout ring to enable containment of radioactive materials collected in the HEPA during filter replacement activities. Each filter is sized to handle 100% of the total syngas flow.

High Performance Centrifugal Fan. Two high efficiency radial blade fans, piped in parallel, provide the required draft on the PEM™ process chamber and the entire syngas processing train to ensure adequate vacuum is maintained in the overall system and that the required flow of syngas is maintained. If one fan fails the other fan starts to maintain a draft through the system. Both of the two fans are identical, and each can handle the entire flow of gases through the system. Each fan is variable speed and controls the plenum pressure.

3.4.3 Third Stage Syngas Converter (Optional - Used when the syngas is not being used to fuel a genset)

IET can provide various options for final disposition of the scrubbed and filtered syngas. Figure 1 shows a thermal syngas converter for thermally oxidizing the syngas to mainly water and carbon dioxide. This is the configuration planned for the ATG PEM^{TM}/GASVIT^{TM} being installed for treating DOE mixed wastes. Other available options include using the syngas as a fuel in an internal combustion engine with an electric generator (engine-generator set, or “genset”) to generate electrical power. If a

genset it not used for syngas combustion and power generation, the syngas may be oxidized or otherwise utilized by other means.

The ATG PEM™/GASVIT™ syngas converter consists of two reinforced, insulated bed chambers filled with ceramic heat exchange media. The syngas flow cycles between two beds at regular intervals, which results in a high degree of heat recovery. The converter requires supplemental heat to reach the operating temperature only during system start-up. The converter does not require any supplemental heat during normal operation. The system exhaust gas leaves the converter and passes through a quench tower prior to entering the stack.

3.5 Utility Subsystems

The PEM™ system provides ancillary service for proper operation of the system. Utility subsystems include: Service/instrument air, nitrogen supply, process water supply, de-ionized water supply, steam, process cooling water, and chilled water. These subsystems have a set of monitors and alarms that measure various parameters regarding the availability and condition of utility services and supply. These monitors and alarms are annunciated in the main process control panel for operator action.

4.0 PEM™ SYSTEM OPERATING MODES AND PROCEDURES

The PEM™ system may operate in various different modes during which different operating conditions will exist. There are two startup modes, (a) startup from a cold standby or first time startup, or (b) startup from hot standby under normal operating conditions or under a recovery scenario after an automatic waste feed cutoff (AWFCO) event. . Different operating modes include (a) idling, (b) hot stand-by, (c) waste processing mode, and (d) AWFCO mode. Different shut-down modes include (a) shutdown from waste processing mode to hot standby mode, (b) shutdown to idling mode, and (c) cold shutdown.

4.1 System Start-up

The PEM™ system requires startup from cold conditions during the initial system startup or following a system maintenance event. During the cold startup procedure, the system requires auxiliary-heating elements (pre-heater) strategically placed within the process chamber. This allows for a controlled temperature increase during startup operations. Once the temperature in the primary process chamber reaches a level at which the glass in the hearth becomes electrically conductive, an electric path between the joule heating electrodes exists. As the process chamber temperature continues to rise, the fraction of heating shifts from the startup pre-heater elements to the joule heating electrodes. Once a condition exists where all the idling power can be supplied by joule heating, the startup pre-heater elements are removed from the process chamber, and the system is in an idle condition. If waste processing activities are not being conducted the PEM™ process will always be idling in the joule-heated operational mode.

4.2 PEM™ System Readiness Modes

When waste is not being processed, the PEM™ system is in one the following readiness modes: Idling, hot stand-by or AWFCO. Each one of these modes is described below.

4.2.1 System Idling Mode

The PEM™ system is placed in an idle mode during system maintenance, or other prolonged scheduled process feeding shutdowns. Process idling can be conducted for extended periods of time if desired. When the system is in idle mode, the following general conditions are maintained:

1. The joule heating system is used to control the temperature in the process chamber.
2. Temperature of molten bath is kept between 880ºC and 1100ºC.

3. Process chamber vacuum is kept at (–) 2 inches of water.
4. First and second stage syngas subsystems are placed in idle mode.
5. A constant flow of nitrogen is introduced into the process chamber environment to keep the system in an inert (i.e., nitrogen atmosphere) condition. This condition provides corrosion protection for key components such as the joule-heated electrodes.

4.2.2 Hot Stand-By Mode

The PEM™ process is placed in hot standby mode during short feeding interruptions. At hot stand-by mode the system is ready to process waste. To convert the PEM™ system from an idling to hot stand-by mode, the melt temperature is raised to normal processing temperatures, and startup of the plasma arc operation and required subsystems is done according to the following sequence:

1. Use Joule heating to raise the process chamber glass temperatures to the normal operating range of 1,200^{o}C to 1,450^{o}C.
2. Ensure that nitrogen supply system is fully operational and appropriate purging is introduced to the plasma arc electrode enclosure, joule heating electrodes, and process chamber.
3. Ensure that steam supply is available to main process chamber steam injector and to first stage syngas processing system.
4. Confirm normal operation of first stage syngas process subsystem including all secondary solids filtration systems
5. Confirm normal operation of second stage syngas process subsystem including all secondary solids filtration systems
6. Confirm normal operation of third stage syngas process subsystem
7. Confirm normal operation of cooling water supply system
8. The DC arc system start-up procedure is initiated. Prior to operation of the DC plasma arc system all subsystem operational parameters must be within the specified ranges.

9. Start the steam feed subsystem.
10. System is ready to receive feed material via one of the three feed systems.

Once the plasma arc has stabilized, and the temperature in the process chamber is in the specified range (i.e. 1,800ºF to 2,700ºF) feeding of the PEM™ process can be initiated.

4.2.3 AWFCO Mode

When an AWFCO event has caused the interruption of waste processing, the system reverts to a hot stand-by as described in the previous section. Prior to starting waste processing, the operator must:

1. Resolve the AWFCO situation.
2. Confirm system readiness parameters listed under the hot-stand by mode.
3. Reestablish all permissive operating parameters.

The system is again ready to receive feed material from one of the three feed systems.

4.3 Waste Processing Mode

Once the PEM™ system parameters are established during the hot stand by mode, waste is fed to the process chamber. During waste processing mode, the operator must monitor the power setting of the joule heating and the plasma heating units to ensure that the chamber temperature is maintained within the operating range. When a processing campaign has been completed, the system is placed in one of the shutdown modes described later on in this section. Molten product is discharged from the process chamber either from a side or bottom drain valve.

4.4 System Shutdown

When waste processing is stopped or when desired by the operator, the system can be shut down and placed in a desired readiness mode as described below.

4.4.1 Shut Down to Hot Stand-By Mode

The system is placed in a hot stand-by mode through the following sequence of shut down steps:

1. Normal processing operation of the system continues until all waste in the process chamber is processed, and all organic constituents are pyrolyzed.
2. All feed systems are isolated and locked out to ensure no additional feed enters the process chamber.

4.4.2 Shut Down to Idling Mode

The system is brought to an idling mode by the following sequence of shutdown steps:

1. Normal processing operation of the system until all waste in the process chamber is processed, and all organic constituents are pyrolyzed.
2. All feed systems are isolated and locked out to ensure no additional feed enters the process chamber.
3. The plasma arc is extinguished, and the electrodes are raised to the idle position.
4. The first and second stage syngas treatment systems are stopped, initiating a flush cycle to clear slurry from piping and scrubber internals.
5. The syngas converter is shut down.

4.4.3 Cold Shutdown

A cold shut down of the PEM™ system is conducted for major system repairs. Cold shut down is conducted after placing the system in idling mode. Next the molten product is drained and the process chamber temperature is gradually reduced to ambient levels.

5.0 CONTINUOUS PROCESS MONITORING AND CONTROL

The PEM™ system is equipped with instrumentation to continuously monitor and control process flows, temperatures, and pressures, and to transmit key signals to the main data acquisition and control system. The system can control valves, motors, pumps, and fans, and can alarm and initiate waste feed cutoff interlocks if process conditions deviate from established limits.

Table 4 lists the major process instrumentation associated with the system. Limited key instrumentation is shown in Figure 1. Those instruments with tag numbers are automatically monitored and controlled to ensure that the system is operated within permit limits. These parameters are also automatically logged via the data acquisition system. Some of these instruments are interlocked with the waste feed system to automatically stop the waste feed if parameters are outside the established limits. During system startup and shutdown or during process upsets, the interlock system automatically prevents all dangerous waste feeds and locks out their restart until the PEM™ system is at proper operating conditions and the interlock is cleared.

In addition to process flowrate, temperature, pressure, and pH monitoring, the syngas composition at the outlet of the ID fans is continuously monitored to provide assurance of safe operating conditions and to provide information for process control and optimization. The syngas is continuously monitored using separate analyzers for CO, CO_2, CH_4, H_2, and O_2. The syngas can also be continuously monitored using a gas chromatograph for He (used as a tracer for flowrate determinations), N_2, and redundant CO, CH_4, H_2, and O_2 measurements.

A centralized main process control (MPC) subsystem encompassing computers, programmable logic controllers (PLCs), Proportional-Integral-Derivative (PID) controllers and other devices is used to monitor control and alarm system parameters relative to operating limits specified in the permit. A brief description of the equipment and software used in the MPC subsystem is presented below.

- **Recorders/Storage.** All data monitored by the MPC/PLC can be stored on electronic media for later use. As a minimum, all Automatic Waste Feed Cut-Off (AWFCO) and feed control parameters specified in the permit operation limits are recorded and stored. The stored data can be recovered by the feed prep, the control room, or the administrative computer. The administrative computer is used for data analysis to ensure permit compliance, and to monitor plant efficiency during a campaign. The Discharge Monitoring panel records its data at a local data logger containing a memory chip. The memory chip can be downloaded into the administrative computer, which along with the loading of the record filter will determine the discharge amount.

- **PLC Controller.** A Siemens 505 Programmable Logic Controller (PLC) is the central controller of the process (MPC/PLC). The PLC contains the controlling logic for the process, as well as the plant monitoring. The Control Room Computer interfaces with the PLC for visual monitoring and operator interface. For redundancy, there is a second standby PLC, to which the process control is transferred if the primary PLC should fail.

- **PID Controllers.** The PID controllers are standalone units that operate with only an input and output signals. The PID controllers are linked to the MPC/PLC network as remote I/O, allowing the operator to view and adjust parameters in the PID controllers from the control room.

Table 4. Continuous process monitors.

Monitored parameter	Tag No. (a)
Feed material inputs	
Additive auger rate, rpm	SI-0110
Total N_2 flowrate, scfm	---
Total steam flowrate, % valve open	---
Total steam flowrate, lb/hr	---
O_2 flowrate, scfm	---
Power inputs	
AC (joule) power inputs: wye or delta	
Electrode 4 current, A	II-0215
Electrode 5 current, A	II-0216
Electrode 6 current, A	II-0217
Electrode 4 line-neutral, V	---
Electrode 5 line-neutral, V	---
Electrode 6 line-neutral, V	---
Power, kW	---
DC (arc) power inputs, current, A	
Electrode 1 current, A	II-0214
Electrode 2 current, A	II-0235
Electrode 3 current, A	II-0236
Electrode 1 line-ref, V	EI-0264
Electrode 2 line-ref, V	EI-0233
Electrode 3 line-ref, V	EI-0234
Power, kW	SI-0237
Slag tap Power, kW:	
1	---
2	---
3	---
Process chamber	
Plenum temperature, ^oC	TI-0115
Pressure, in. H_2O	PIC-0113
Refractory temperatures, ^oC:	
A	TI-0176A
E	TI-0176B
G	TI-0176G
H	TI-0176H
Thermal retention chamber	
Gas temperature T1, ^oC (first)	TI-0176D
Gas temperature T2, ^oC (second)	TI-0176F

Table 4. Continuous process monitors (continued).

Monitored parameter	Tag No. (a)
Partial quench	
Temperature, ^{o}C	TI-0176B
Quench solution flowrate, gpm	---
Baghouse	
Inlet temperature, C	TI-0176C
Differential presssure, in. H_2O	---
Ejector scrubbers	
EVS 1: Liquid flowrate, gpm	
Nozzle pressure, psig	
Packed bed liquid recycle rate, gpm	
pH(x10)	AIC-0601
EVS 2: Liquid flowrate, gpm	
Nozzle pressure, psig	
Packed bed liquid recycle rate, gpm	
Outlet gas temperature, ^{o}C	TI-0621
Offgas flowrate, wscfm	FI-0604
pH(x10)	AIC-0640
Induced draft fans	

ID fan 1 % output	---
ID fan 2 % output (herz)	---
Flame arrestor gas T, ^{o}F	---
Flame arrestor gas comp., % dry: CO	AI-0701
CO2	AI-0702
CH4	AI-0703
H2	AI-0705
O2	AI-0704
Offgas CO/(CO+CO2) ratio	AIC-0712
HEPA filter differential pressure, in. H2O	
Engine generator set (genset)	
Syngas inlet flowrate, wscfm	
Auxiliary fuel (propane) flowrate, scfm	
Combustion air flowrate, scfm	
Power output, kW	

a. Those instruments with tag numbers are also automatically logged via the data acquisition system. Those instruments without tag numbers have a local readout only, or are otherwise not automatically logged, and need to be manually logged during tests that specifies that these data are recorded.

6.0 SAMPLE COLLECTION AND ANALYIS

Sample collection and analysis for generating data to be used in the verification program generally must be according to practices used in trial burns and other performance tests where the results need to have known quality and comparability. Sample collection and analysis during demonstration tests are to be conducted in accordance with procedures specified in the Quality Assurance/Quality Control Project Plan for the ATG GASVIT Demonstration Test (dated October 20, 1997).

Process and offgas samples can be collected noncontinuously as specified by test plans. Table 5 summarizes potential sample collection descriptions, and procedures. The sample locations are shown in Figure 2. Sample analysis procedures that may be included in test plans are summarized in Table 6.

7.0 APRIL 2000 DEMONSTRATION TESTING

PEM™ system demonstration tests were conducted during April 2000. Two test series were conducted to (a) determine PEM^{TM} system equivalency to incineration to met requirements for this system to be installed as the ATG GASVIT^{TM} system in the mixed waste treatment facility in Hanford, Washington, (b) provide test data for a unique, circuit-board fabrication waste material, and (c) provide test data for the EvTEC verification program.

These tests were performed based on the then-current draft of the EvTEC test plan (IET 2000) and based on equivalency test objectives defined by ATG, Focus Environmental, and EPA Region 10. Focus Environmental prepared the trial burn plan for the GASVIT^{TM} system, and prepared much of the then-current draft EvTEC test plan. Focus personnel directed the equivalency test on behalf of ATG, and assisted in the circuit-board fabrication waste tests. In this way, both test series were performed using sampling and analysis procedures that were consistent with the draft test plan and also consistent with the quality assurance plan associated with the draft trial burn plan for the GASVIT^{TM} system. The offgas sample collection and analysis for both test series was performed by AmTest and analytical laboratories subcontracted to AmTest. IET personnel collected feed and process samples and shipped those samples to outside laboratories for specified laboratory analyses.

Table 5. Sample collection locations, equipment, and methods (formerly Table 2.4).

Location[a]	Sample Name	Access	Equipment	Sample Size	General Procedure/Frequency	Reference Method[b]
1	Liquid waste feed (1- properties) (1 - archive)	Tap	4 literglass bottle, 4 oz glass jars, 250 ml glass bottles	4 oz. per grab; 250 ml properties 250 ml archive	One grab sample collected every 15 minutes during Test Condition 1 and composited in the field to form one sample per run. Fill two 250 ml bottles from the composite after the run.	ASTM E 300-86, Sect. 23 and 24
2	Containerized solid waste feed (1 - properties) (1 - metals) (1 - archive)	Open top	Scoop, large bowl or bucket, 500 ml wide-mouth glass bottles	1 scoop per grab; 500 ml properties 500 ml metals 500 ml archive	Prior to the Demonstration Test, collect at least seven scoops of the stockpiled material. Mix well in bowl or bucket. Fill three 500 ml bottles from the bowl or bucket.	ASTM E 300-86, Sect. 30
3	Bulk solid waste feed (1 - properties) (1 - metals) (1 - archive)	Open top	Scoop, large bowl or bucket, 500 ml wide-mouth glass bottles	1 scoop per grab; 500 ml properties 500 ml metals 500 ml archive	Prior to the Demonstration Test, collect at least seven scoops of the stockpiled material. Mix well in bowl or bucket. Fill three 500 ml bottles from the bowl or bucket.	ASTM E 300-86, Sect. 30
NA	PCB spiking material (1 - PCBs) (1 - properties) (1 - archive)	Tap	250 ml glass bottles	250 ml PCBs 250 ml properties 250 ml archive	Prior to the Demonstration Test, collect three 250 ml bottles of the PCB spiking material before it is mixed with the other organic spiking materials.	ASTM E 300-86, Sect. 23 and 24
NA	Flux material (1 - properties) (1 - metals) (1 - archive)	Open top	Scoop, large bowl or bucket, 500 ml wide-mouth glass bottles	1 scoop per grab; 500 ml properties 500 ml metals 500 ml archive	Prior to the Demonstration Test, collect at least seven scoops of the stockpiled material. Mix well in bowl or bucket. Fill three 500 ml bottles from the bowl or bucket.	ASTM E 300-86, Sect. 30
NA	PODC and metal spiking materials	Open top	Thief, 500 ml wide-mouth glass bottles	500 ml archive of each material	Prior to the Demonstration Test, collect 500 ml of each spiking material and archive for analysis if needed.	ASTM E 300-86, Sect. 23 and 24
4a	Vitrified product – Bottom tap (1 - SVOC/PCB) (1 - metals) (1 - archive)	Tap	Crucible, grinder, 500 ml glass bottles.	500 ml SVOC/PCB 500 ml metals 500 ml archive	Allow molten material to flow from the tap into the crucible every 30 minutes during each run of the Demonstration Test. At the end of the run, grind the cooled material into small uniform granules. Fill three 500 ml bottles with the ground material.	ASTM E 300-86, Sect. 30
4b	Vitrified product - Overflow tap (1 - SVOC/PCB) (1 - metals) (1 - archive)	Tap	Crucible, grinder, 500 ml glass bottles.	500 ml SVOC/PCB 500 ml metals 500 ml archive	Allow molten material to flow from the tap into the crucible every 30 minutes during each run of the Demonstration Test. At the end of the run, grind the cooled material into small uniform granules. Fill three 500 ml bottles with the ground material.	ASTM E 300-86, Sect. 30
5	Scrubber blowdown (1 - SVOC/PCB) (1- metals) (1- archive)	Tap	500 ml glass jar, 4 liter glass bottle, 1 liter glass bottles	500 ml per grab; 1 l SVOC/PCB 1 l metals 1 l archive	One grab sample collected every 30 minutes during each run of the Demonstration Test. Composite in the field to form one sample per run. Fill three 1 liter bottles from the composite at the end of each run.	ASTM E 300-86, Sect. 23 and 24
	Scrubber blowdown (1- VOC)	Tap	Glass VOA vials	~40 ml per vial	Fill two VOA vials every 30 minutes during each run of the Demonstration Test. Samples from each run will be composited in the lab just prior to analysis.	ASTM E 300-86, Sect. 23 and 24
6a	System exhaust M0050	Port	SW-846 Method 0050 sampling train	Minimum 120 minutes[c]	Collect integrated sample of particulates, hydrogen chloride, chlorine, and moisture during each run of the Demonstration Test. Measure stack gas velocity, pressure, and temperature. Collect bag samples or use CEM for molecular weight determination.	SW-846 Method 0050

Table 5. Sample collection locations, equipment, and methods (formerly Table 2.4).

Location[a]	Sample Name	Access	Equipment	Sample Size	General Procedure/Frequency	Reference Method[b]
6b	System exhaust PSD	Port	EPA Method 5 sampling train	Maximum of 30 cubic feet	Collect integrated sample of particulates and moisture during each run of the Demonstration Test. Measure stack gas velocity, pressure, and temperature. Collect bag samples or use CEM for molecular weight determination.	EPA Methods 1 - 5
6c	System exhaust M0031	Port	SW-846 Method 0031 sampling train	4 tube sets per run. Up to 20 liters of stack gas per tube set.	Collect four sets of sorbent tubes and stack gas condensate for volatile organics during each run of the Demonstration Test.	SW-846 Method 0031
6d	System exhaust M0040	Port	SW-846 Method 0040 sampling train.	25 to 35 litres	Collect representative sample through a heated sample probe and filter; through a condeser and into a Tedlar bag for total volatile organics during each run of the Demonstration Test.	SW-846 Method 0040
6	System exhaust M0023	Port	SW-846 Method 0023 sampling train	Minimum 3 dry standard cubic meters[c]	Collect integrated sample for PCDD/PCDF, SVOC, PCBs, and moisture during each run of the Demonstration Test. Measure stack gas velocity, pressure, and temperature. Collect bag samples or use CEM for molecular weight determination.	SW-846 Method 0023
6f	System exhaust M0010	Port	SW-846 Method 0010 Sampling train	Minimum 3 dry standard cubic meters[c]	Collect integrated sample for total semivolatile organics, total nonvolatile organics, and moisture during each run of the Demonstration Test. Measure stack gas velocity, pressure, and temperature. Collect bag samples or use CEM for molecular weight determination.	SW-846 Method 0010
6g	System exhaust M0061	Port	SW-846 Method 0061sampling train	Minimum 120 minutes[c]	Collect integrated sample for hexavalent chromium and moisture during each run of Test Condition 1 and 2. Measure stack gas velocity, pressure, and temperature. Collect bag samples or use CEM for molecular weight determination.	SW-846 Method 0061
6h	System exhaust M0060	Port	SW-846 Method 0060 sampling train	Minimum 120 minutes[c]	Collect integrated sample for metals and moisture during each run of Test Condition 1 and 2. Measure stack gas velocity, pressure, and temperature. Collect bag samples or use CEM for molecular weight determination.	SW-846 Method 0060

[a] Sampling locations refer to Figure D-5b3.

[b] "ASTM" refers to American Society for Testing and Materials, Annual Book of ASTM Standards.
"EPA Method" refers to New Source Performance Standards, Test Methods and Procedures, Appendix A, 40 CFR 60.
"SW-846" refers to Test Methods for Evaluating Solid Waste, Third Edition, November 1986, and Updates.

[c] The exact volume of gas sampled will depend on the isokinetic sampling rate.

Table 6. Summary of potential analytical procedures (formerly Table 2.18).

Sample Name	Analysis	Preparation Method	Analytical Method
Liquid waste feed	Ash content	NA	Muffle furnace (ASTM D482)
	Total chlorine/chloride content	Combustion/absorption (SW846-5050)	Ion chromatography (SW846-9056)
	Heating value	NA	Calorimeter (ASTM D240)
	Viscosity	NA	Viscometer (ASTM D445)
Bulk solid waste feed	Ash content	NA	Muffle furnace (ASTM D482)
	Total chlorine/chloride content	Combustion/absorption (SW846-5050)	Ion chromatography (SW846-9056)
	Heating value	NA	Calorimeter (ASTM D2015)
	Total metals	Acid digestion (SW846-3051)	ICP (SW846-6010); CVAAS for Hg (SW846-7471)
Containerized waste feed	Ash content	NA	Muffle furnace (ASTM D482)
	Total chlorine/chloride content	Combustion/absorption (SW846-5050)	Ion chromatography (SW846-9056)
	Heating value	NA	Calorimeter (ASTM D2015)
PCB spiking material	PCBs	Solvent extraction (SW846-3500 series)	GC/ECD (SW846-8082)
	Total chlorine/chloride content	Combustion/absorption (SW846-5050)	Ion chromatography (SW846-9056)
Flux material	Ash content	NA	Muffle furnace (ASTM D482)
	Total chlorine/chloride content	Combustion/absorption (SW846-5050)	Ion chromatography (SW846-9056)
	Total metals	Acid digestion (SW846-3051)	ICP (SW846-6010); CVAAS for Hg (SW846-7471)
Vitrified product (overflow tap and bottom tap)	Semivolatile PODCs	Solvent extraction (SW846-3500 series)	GC/MS (SW846-8270)
	PCBs	Solvent extraction (SW846-3500 series)	GC/MS (EPA-680)
	Total metals	Acid digestion (SW846-3051)	ICP (SW846-6010); CVAAS for Hg (SW846-7471)
	TCLP metals	Leaching (SW846-1311)	ICP (SW846-6010); CVAAS for Hg (SW846-7470)
Scrubber blowdown	Volatile PODCs	Purge and trap or direct injection	GC/MS (SW846-8260)
	Semivolatile PODCs	Solvent extraction (SW846-3500 series)	GC/MS (SW846-8270)
	PCBs	Solvent extraction (SW846-3500 series)	GC/MS (EPA-680)
	Total metals	Acid digestion (SW846-3015)	ICP (SW846-6010); CVAAS for Hg (SW846-7470)
System exhaust M0031	VOCs + TICs (tenax + Anasorb tubes)	Thermal desorption, trap (SW846-5041)	GC/MS (SW846-5041)
	VOCs + TICs (condensate)	Purge and trap	GC/MS (SW846-8260)
System exhaust M0040	Total VOCs	Purge and trap for condensate; Direct injection for gas	GC/FID (Guidance for Total Organics, Appendices A and E)
System exhaust M0023	PCDD/PCDF	Solvent extraction (SW846-	GC/MS (EPA Method 23, SW846-8290)

Table 6. Summary of potential analytical procedures (formerly Table 2.18).			
Sample Name	Analysis	Preparation Method	Analytical Method
		8290)	
	SVOCs +TICs	Solvent extraction (SW846-3500 series)	GC/MS (SW846-8270)
	PCBs	Solvent extraction (SW846-3500 series)	GC/MS (EPA-680)
	Moisture	NA	Gravimetric (EPA Method 4)
	Oxygen, carbon dioxide, carbon monoxide, hydrogen	NA	Continuous monitor
	Temperature	NA	Thermocouple (EPA Method 2)
	Flow rate	NA	Pitot tube (EPA Method 2)
System exhaust M0010	Total SVOCs	Solvent extraction (SW846-3542)	TOC GC/FID (Guidance for Total Organics, Appendix C)
	Total NVOCs	Solvent extraction (SW846-3542)	Gravimetric (GRAV) Method (Guidance for Total Organics, Appendix D)
	Moisture	NA	Gravimetric (EPA Method 4)
	Oxygen, carbon dioxide, carbon monoxide, hydrogen	NA	Continuous monitor
	Temperature	NA	Thermocouple (EPA Method 2)
	Flow rate	NA	Pitot tube (EPA Method 2)
System exhaust M0050	Particulate	Evaporate/dessicate (EPA Method 5)	Gravimetric (EPA Method 5)
	Chloride (acid and base impingers)	NA	Ion chromatography (SW846-9057)
	Moisture	NA	Gravimetric (EPA Method 4)
	Oxygen, carbon dioxide, carbon monoxide, hydrogen	NA	Continuous monitor
	Temperature	NA	Thermocouple (EPA Method 2)
	Flow rate	NA	Pitot tube (EPA Method 2)
System exhaust PSD	Particle size distribution	NA	Gravimetric (EPA Method 5); Scanning electron microscopy
	Moisture	NA	Gravimetric (EPA Method 4)
	Oxygen, carbon dioxide, carbon monoxide, hydrogen	NA	Continuous monitor
	Temperature	NA	Thermocouple (EPA Method 2)
	Flow rate	NA	Pitot tube (EPA Method 2)

Table 6. Summary of potential analytical procedures (formerly Table 2.18).

Sample Name	Analysis	Preparation Method	Analytical Method
System exhaust M0061	Hexavalent chromium	NA	Ion chromatography, post-column reactor (SW846-7199)
	Moisture	NA	Gravimetric (EPA Method 4)
	Oxygen, carbon dioxide, carbon monoxide, hydrogen	NA	Continuous monitor
	Temperature	NA	Thermocouple (EPA Method 2)
	Flow rate	NA	Pitot tube (EPA Method 2)
System exhaust M0060	Metals [a]	Acid digestion	Inductively coupled argon plasma emission spectroscopy (ICAP) (SW846-6010) or graphite furnace atomic absorption (GFAA) spectroscopy (SW846-7000 series). Mercury by cold vapor atomic absorption (CVAA) (SW846-7471)
	Moisture	NA	Gravimetric (EPA Method 4)
	Oxygen, carbon dioxide, carbon monoxide, hydrogen	NA	Continuous monitor
	Temperature	NA	Thermocouple (EPA Method 2)
	Flow rate	NA	Pitot tube (EPA Method 2)

[a] Metals: Sb, As, Ba, Cd, Cr, Cu, Pb, Mn, Ni, Ag, Se, V, Tl; Radionuclide surrogates: Ce and Cs.

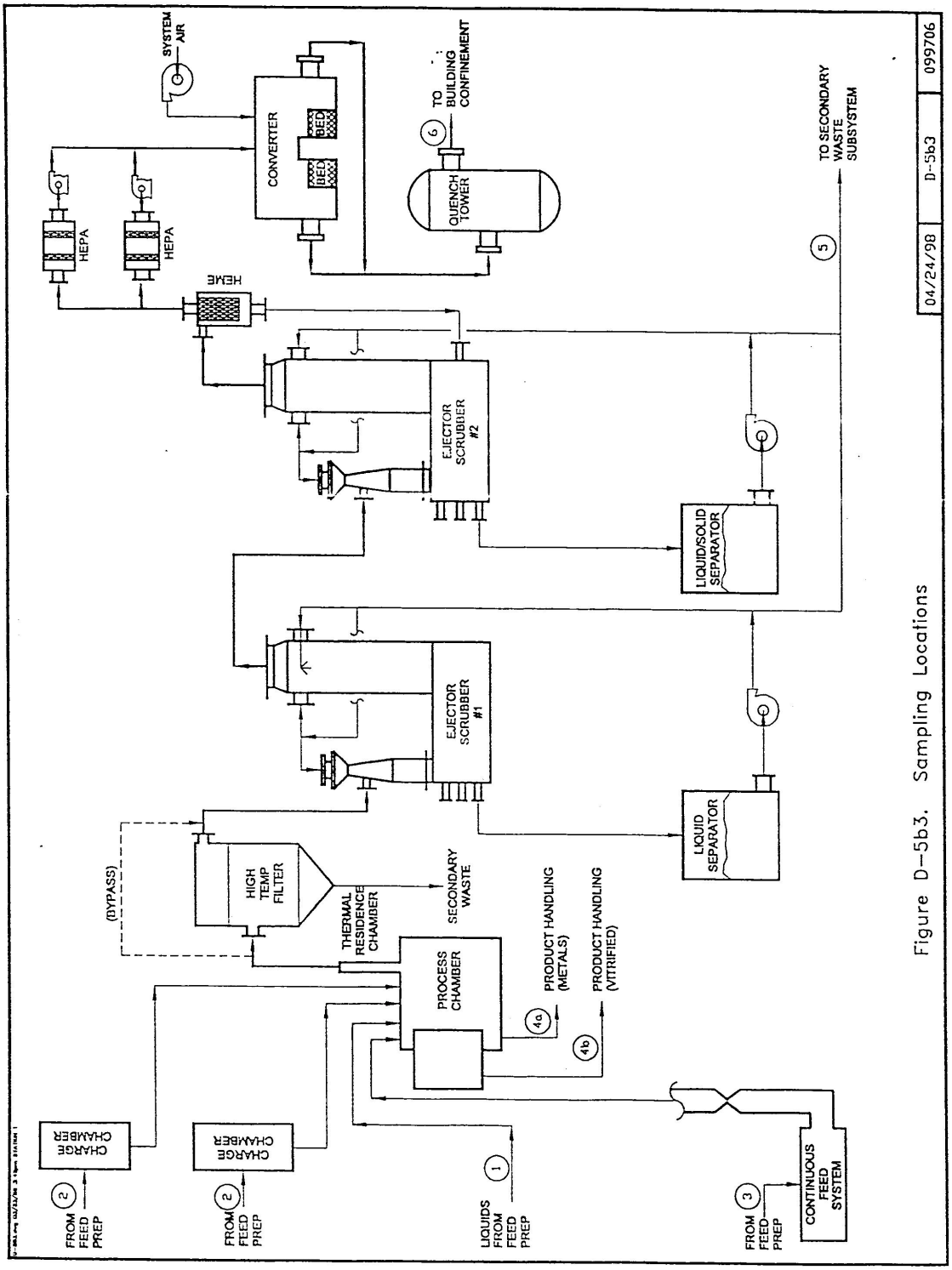

Figure 2. Locations of sample collection points (Formerly Figure D5b-3).

Results of these tests can provide data for evaluation with respect to many, but not all, of the criteria listed in Section 2. Criteria that these test data address are identified in Table 1. Test results will be provided to the EvTec verification via written report from IET, Focus Environmental, and AmTest.

Mr. Nick Soelberg, Evaluation Panel member and EvTEC consultant, observed both test series. The EvTEC Project Manager, Ms. Heather Warkentien, and the ETV Pilot Manager, Ms. Norma Lewis, observed much of the first test series, which was the equivalency tests.

Each of the test series are described briefly below. More detail of the test activities and test results will be provided in the IET/Focus/AmTest report, which should be available for EvTEC review in the summer of 2000.

7.1 Test Series 1 – PEM™/GASVIT™ Equivalency Tests

The primary objective of the equivalency tests was to determine PEM™ equivalency to incineration for this system to be installed as the ATG GASVIT™ system in the mixed waste treatment facility in Hanford, Washington. Specific test activities to meet this objective were defined by ATG, IET, and EPA Region 10. The system would be deemed equivalent to incineration if it could:

- Destroy selected principal organic dangerous constituents (PODCs) with an efficiency of at least 99.99%

- Destroy polychlorinated biphenyls (PCBs) with an efficiency of 99.9999%

- Achieve at least 99% HCl control

- Control particulate matter (PM) to meet a PM emission limit of 0.08 grains/dscf, corrected to 7% O_2.

These equivalency criteria were defined in draft test plans prior to promulgation of the Maximum Achievable Control Technology (MACT) standards for hazardous waste combustors in September 1999. The ATG GASVIT™ system has been designed to comply with these MACT standards, and so will need

to meet additional and more restrictive standards as shown in Table 2. The PM emission limit has been lowered to 0.015 grains/dscf, the MACT limit for total HCl/Cl_2 emissions is 21 ppmv (at 7% O_2) for new sources, and there are additional emission standards for D/Fs, HC (using either HC or CO continuous monitoring), SVMs, LVMs, and Hg. Since equivalency to incineration has been defined according to the above-listed criteria, the equivalency test series will demonstrate how well the PEM™ system complies with MACT PM, HCl/Cl_2, D/F, CO, and HC standards in addition to the above-listed criteria. The scope of the equivalency testing included:

- A surrogate liquid organic waste was fed to the melter, in which a molten slag bath was already established. The surrogate feed was methanol spiked with PCBs and the PODC surrogates monochlorobenzene (a chlorinated, aromatic, relatively stable volatile organic compound) and naphthalene (a relatively stable polycyclic aromatic hydrocarbon (PAH)).

- The system operating conditions were set such that reasonably worst-case conditions prevailed that could cause lower destruction efficiencies of the organic compounds. System operation within the envelope defined by these worst-case conditions should then be expected to have as good if not better destruction efficiencies for those compounds.

- Process control, monitoring, and data logging was performed to maintain and document the design operating conditions.

- Process sample collection was performed to obtain process samples such as surrogate feed and scrub solution samples for analysis. Since no slag-forming feed materials were fed to the furnace, there was no slag or metal tapping, and no slag or metal product samples were collected for analysis.

- The scrubbed and filtered syngas produced in the process was oxidized in a ground flare used to simulate the thermal syngas converter planned for the GASVIT™ process. The oxidized offgas was then discharged to the atmosphere, as it would be for the the GASVIT™ process. Sampling and analysis of the oxidized offgas was performed to determine emissions of (a) VOCs including the PODC monochlorobenzene using Method 0031, (b) SVOCs including the PODC naphthalene, D/Fs, and PCBs using Method 0023/0010, and (c) HCl, Cl_2, and PM using Method 0050 modified to include the PM analysis. The oxidized offgas was also continuously monitored for O_2, CO_2, CO, NO_x, SO_2, and THC.

The performance of the PEM™ in meeting other MACT standards (Hg, SVM, and LVM emission limits) was outside the scope of the equivalency tests because (a) compliance with these MACT standards for metals emissions was not considered necessary to show incinerator equivalency, (b) the feed material did not include these constituents, and (c) no offgas sampling for metals was done in order to control the cost and schedule for the equivalency tests. The ability of the system to meet Hg, SVM, and LVM standards can be demonstrated during the ATG GASVIT™ trial burn, when feed materials that contain these constituents will be fed into the system.

During the April 2000 demonstration tests, the syngas was oxidized in either an enclosed ground flare or was used as a fuel in an internal combustion engine to produce electrical power using an electric generator (engine-generator set, or "genset"). The syngas was flared during the organics destruction and removal efficiency (DRE) tests used to determine equivalency for the ATG PEM™/GASVIT™ system. The syngas was used as genset fuel to produce electrical power during the printed circuitboard waste feed tests. The oxidized offgas from the ground flare and from the genset was discharged to the atmosphere. During both tests, selected sampling and analysis was performed on the offgas to determine concentrations, emission rates, and destruction or control efficiencies for various pollutant emissions.

7.2 Test Series 2 – Circuitboard Fabrication Waste Test

The circuitboard fabrication waste tests were conducted to demonstrate the capability of the PEM™ system to treat this unique waste material and comply with potentially applicable emission regulations such as the MACT standards for hazardous waste combustion. This waste material consists mainly of scraps and sheets of fiberglass board with a coating of copper on one side. This material does not contain solder, electronic components, or other materials common to electronic circuit boards. The scope of this test series was defined to demonstrate the overall system performance:

- The solid circuitboard waste was fed to the furnace, in which a molten slag bath was already established.

- The system was operated at reasonably nominal conditions. Parametric evaluations of operating conditions were not within the scope of this test series.

- Process control, monitoring, and data logging was performed to maintain and document the design operating conditions.

- Process sample collection was performed to obtain process samples such as waste feed and scrub solution samples for analysis. Since very little slag-forming feed materials were fed to the furnace, there was no slag or metal tapping, and no slag or metal product samples were collected for analysis.

- Operation with the engine-generator set ("genset") was demonstrated by cofiring a portion of the scrubbed and filtered syngas produced by the process in a genset. The remainder of the syngas was was oxidized in a ground flare before discharge to the atmosphere. The genset was initially started and stabilized on propane fuel, and then syngas was cofired with the propane during this test series. Sampling and analysis of the genset offgas was performed to determine emissions of (a) VOCs using Method 0031, (b) SVOCs including D/Fs using Method 0023/0010, and (c) HCl, Cl_2, and PM using Method 0050 modified to include the PM analysis. The genset offgas was also continuously monitored for O_2, CO_2, CO, NO_x, SO_2, and THC.

The scope of offgas sample collection and analysis was capable of showing compliance to such emission standards as the MACT standards for Hg, PM, HCl/Cl_2, SVM, LVM, HC, and CO emissions. Since no Hg or PCBs were in the feed, these analyses were not included in the scope of testing.

8.0 REFERENCES

IET 1998, "EvTEC Test Plan, Plasma Enhanced Melter™/GASVIT™," September 13, 1998.

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Focus Environmental 1997, Quality Assurance/Quality Control Project Plan, ATG GASVIT Demonstration Test, October 20, 1997.